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NON-DESTRUCTIVE TESTING
OF
INTERCONNECTIONS AND MICROJOINTS

Final Report

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by

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CONTENTS

	Introduction	1
PART ONE -	Nondestructive Testing System for Wire Weld Evaluation	5
I	Prototype NDT System Evaluation	5
II	Prototype NDT System Evaluation Discussion	10
III	Conclusions	22
PART TWO -	Possible Applications of Nondestructive Testing to Microjoints	25
APPENDIX A -	Detailed Discussion of Bonding Methods and Basic Metallic Systems Used	34
	I Bonding Methods	34
	II Metal Systems	45
	III Packaging	53
APPENDIX B -	Effectiveness of NDT Verbal Presentations	64
APPENDIX C -	Organizations Visited for Verbal Presentation	69

INTRODUCTION

This is the final report on the Non-Destructive Testing Program being conducted for the National Aeronautics and Space Administration, Ames Research Center (NASA/ARC) under Phase II of Contract NAS 2-4166. This program has resulted in the successful development of nondestructive weld evaluation techniques and instrumentation for ultimate application in the field of high reliability electronic circuit and component welding. Further, it has considered in a preliminary way the possibility of applying these techniques to the evolution of microjoints in integrated circuits, and this is discussed in Part Two. A detailed account of the entire program to date may thus be obtained from this report in conjunction with NASA Reports CR73207 and CR73385.

In addition to the status reports published throughout this program, a series of verbal reports has been presented on site to selected industrial and NASA organizations. A list of the organizations visited and the attendance at each place is provided in Appendix A of this report. As a result of this experience it is our opinion that the method of disseminating information by direct personal presentation to interested organizations has several distinct advantages over the more conventional means of written reporting. In our judgment, information resulting from future R&D programs that may be considered of immediate benefit to industry in general should be conveyed by means of verbal presentations. In this way the program gets maximum exposure and the techniques developed can be more promptly applied by industry. A more detailed account of our experiences in this regard is presented in Appendix B.

Specifically treated in this report are the results of the prototype instrumentation evaluation program recently completed and information derived from a study program initiated to determine the feasibility of utilizing in other applications the cross-wire nondestructive test (NDT) concepts and methods already developed.

The study program referenced above was undertaken to provide the basis for a well-directed additional program to expand the existing NDT capability into other areas, possibly involving different bonding methods. During the study, particular emphasis was on Integrated Circuit (I.C.) manufacturing technology. As will be seen in the text that follows, a survey of I.C. manufacturers and users shows that bonding problems are a prime cause of I.C. failure, both during the manufacturing cycle and in the field. Of particular interest are those device failures that occur in the field. Such devices have obviously had all the conventional techniques of inspection, test, and quality control applied with the result that latent bonding failures escaped detection. Thus, the need to develop an effective NDT technology that will enable these latent bonding defects to be located during the manufacturing cycle and prior to their installation in hardware with critical operating reliabilities and lifetimes would seem essential.

PART ONE

NONDESTRUCTIVE TESTING SYSTEM FOR WIRE WELD EVALUATION

I. PROTOTYPE NDT SYSTEM EVALUATION

A. Background Information

The NDT program has been conducted over a period of approximately two years and has involved both laboratory studies and the evaluation of prototype NDT systems in the production lines of two large aerospace manufacturers. The program has thus far involved the fabrication and testing of a total of 45,000 individual welds. Of these, 33,000 were tested in production and 12,000 were actually pull-tested to destruction in our laboratory. The material types used in the 33,000 production welds are shown in Table 1, on page 14.

The specific system to be discussed herein measures setdown, infrared, and weld pulse during the time the weld is being made; compares these measurements to previously established criteria for good welds between a given pair of materials; and accepts or rejects the weld on the basis of this comparison. This approach therefore offers the possibility of establishing uniform weld acceptance criteria, substantial reductions in visual inspection requirements, and the realization of a high degree of reliability in the welds accepted by the system.

B. Prototype Design*

The prototype weld evaluator, in the present configuration,

*A more detailed treatment of the NDT design, including drawings, may be found in NASA Report CR73385.

measures the weld attributes previously discussed and compares each of these attributes with prescribed electrical acceptance limits which are stored in the weld evaluator. Based on these comparisons, it then determines that the weld is or is not satisfactory. The comparison performed by the NDT system does not produce any detrimental effects on the character of the weld. Thus it performs an instantaneous, nondestructive examination of each individual weld and presents a visual indication of weld acceptability to the operator.

The following items were considered to constitute the primary criteria for the design and implementation of the NDT systems:

- <u>Noninterference with the operator</u> -- The instrumentation must not interfere with the normal welding operation in any way. This meant that the operator's view of the weld area must not be impaired in any manner; the normal operator manipulations of the weld material with respect to the electrodes must not be interfered with; and accessibility of electrodes and other welder parts for maintenance purposes must not be impeded.

- <u>No effect on welding characteristics</u> -- The instrumentation must not interfere with welding characteristics in any manner. This would be of particular concern in instrumenting setdown, where electrode movement must be transduced into voltage without degrading electrode follow-up characteristics of the welding head.

- <u>Minimum complexity</u> -- In order to facilitate initial installation of instrumentation, calibration, and maintenance, the actual application must be as simple as possible. For instance, in instrumentation of infrared radiation the use of sophisticated optics could result in an undesired degree of complexity.

- <u>Measurement integrity</u> -- The prototype system must successfully implement the NDT concept demonstrated as feasible during the Phase I studies. In order to accomplish this, the system should have sufficient measurement accuracy and operational stability to ensure that no degradation of NDT concept effectivity results.

- <u>Results to the operator</u> -- The system must present weld evaluation results to the operator and/or supervisor in a simple, obvious fashion. Again this indication must be accomplished with little or no interference with normal operations.

The major electrical requirements to be accommodated are itemized below:

- Measure the peak values of the three attributes.

- Compare the peak values with the prescribed limits.

- Determine the number of attributes which exceed their boundaries. If two or more attributes exceed the prescribed boundaries, indicate that the weld is "not acceptable." If less than two attributes exceed their prescribed boundaries, indicate that the weld is "acceptable." In addition, should the amount of deformation exceed that defined as "excessive deformation," or should the weld be produced with reverse polarity setting, the weld evaluator must indicate that the weld is "not acceptable," regardless of the status of the other attributes.

- Indicate the results of the comparisons to the operator and/or supervisor.

- The NDT system must perform the functions listed above while operating in a production environment with the associated electrical noise and primary A.C. power line perturbations.

The prototype system that was developed meets all of these requirements. Basically, the system that was evolved consists of a transducer subsystem, sampling subsystem, acceptance limits subsystem, and the necessary power supplies.

The transducer assembly is affixed to the welder head and contains a strain gauge beam assembly to measure setdown, a photovoltaic cell that measures infrared radiation and terminals to sample the weld pulse voltage.

The sampling subsystem contains the circuitry required for signal sampling and comparing, the timing and control circuits, and the output control logic. The major portion of the sampling subsystem design employs special digital circuitry to assure stable, accurate, and reliable operation in the electrically-noisy production environment.

The acceptance limit voltages for each of the measured weld attributes are derived from the acceptance limits subsystem. The unit provides five sets of adjustable and selectable high and low limits for each attribute as well as the excessive setdown limit. These signals are fed to the sampling subsystem, where they are used as reference signals during the comparison time of the weld evaluation interval.

The necessary operating voltage for the NDT system is provided by the system power supply. This supply operates from the 110 v. AC, 60 Hz available in most manufacturing facilities. The system power supply provides six regulated and filtered DC voltages.

II. PROTOTYPE NDT SYSTEM EVALUATION DISCUSSION

Our evaluation of the prototype NDT systems has been accomplished on the production lines of Lockheed Missiles and Space Company, Sunnyvale (LMSC), and General Dynamics, Pomona (GD/P). The purpose of the evaluation program was to process large quantities of production welds in a manufacturing environment in order to establish the performance integrity and operational reliability of the equipments and to demonstrate the validity of NDT concept as implemented by the prototype systems. Both NASA and WVS are indebted to these companies for permitting the NDT instrumentation to be installed on their regular production lines. Without their active participation and interest a program of this type would not have been as meaningful. The on-site evaluation program consisted of the following major events:

- NDT system installation and checkout.
- Weld acceptance limit derivation for each measured attribute; i.e., weld pulse, infrared, and setdown.
- Operator training.
- Production weld measurement.
- Concurrent weld measurement data analysis
- NDT effectivity assessment.

A. Module Configurations

The type of modules being manufactured at both LMSC and GD/P were of the three-D cordwood type. Components are mounted between two fiber positioner boards. To facilitate handling, the positioner boards are mounted on a plastic weld frame which is cut off and discarded upon completion of the entire welding operation. Upon removal of the weld frame, the completed module is all that remains.

Two methods of component interconnect were employed. One method routed lengths of nickel ribbon, .012" X .030", between the components to be connected. Components were first welded to their respective ribbon lengths and the operation was completed by trimming off the excess ribbon ends. The other method used pre-assembled nickel wire grids, .020", to connect the components. This technique allowed multi-level assemblies and did not require the operator to route the interconnect material.

The specific materials processed through the NDT stations are tabulated in Tables 1 and 2. As may be seen from the tables, the NDT systems were exercised over a variety of materials and material dimensions. More importantly, however, is the fact that the equipment has been demonstrated over a 16 to 1 range (2.8 w.s.

to 44 w.s.) energy range and two pulse widths. Figure 1 shows the proportionality to total welds made of the four generic lead materials. These materials conservatively account for over 95% of the module welds being made at LMSC and GD/P. Since it is very difficult or impossible to obtain satisfactory welds with copper wire to nickel wire combinations, this material was used exclusively in combination with nickel ribbon. The oxygen free high conductive (OFHC) copper was used on Allen-Bradley resistors. Gold-flashed Kovar lead material was found primarily on transistors and I.C.'s. Dumet appeared mostly on diodes. Many of the parts purchased and controlled exclusively for welding by LMSC came with nickel or gold-flashed nickel leads. Generally speaking, the parts at GD/P were controlled for the dual purpose of welding or soldering.

TABLE 1

MATERIALS USED IN NDT EVALUATION AT LMSC
.020" Bare Nickel Wire Interconnect

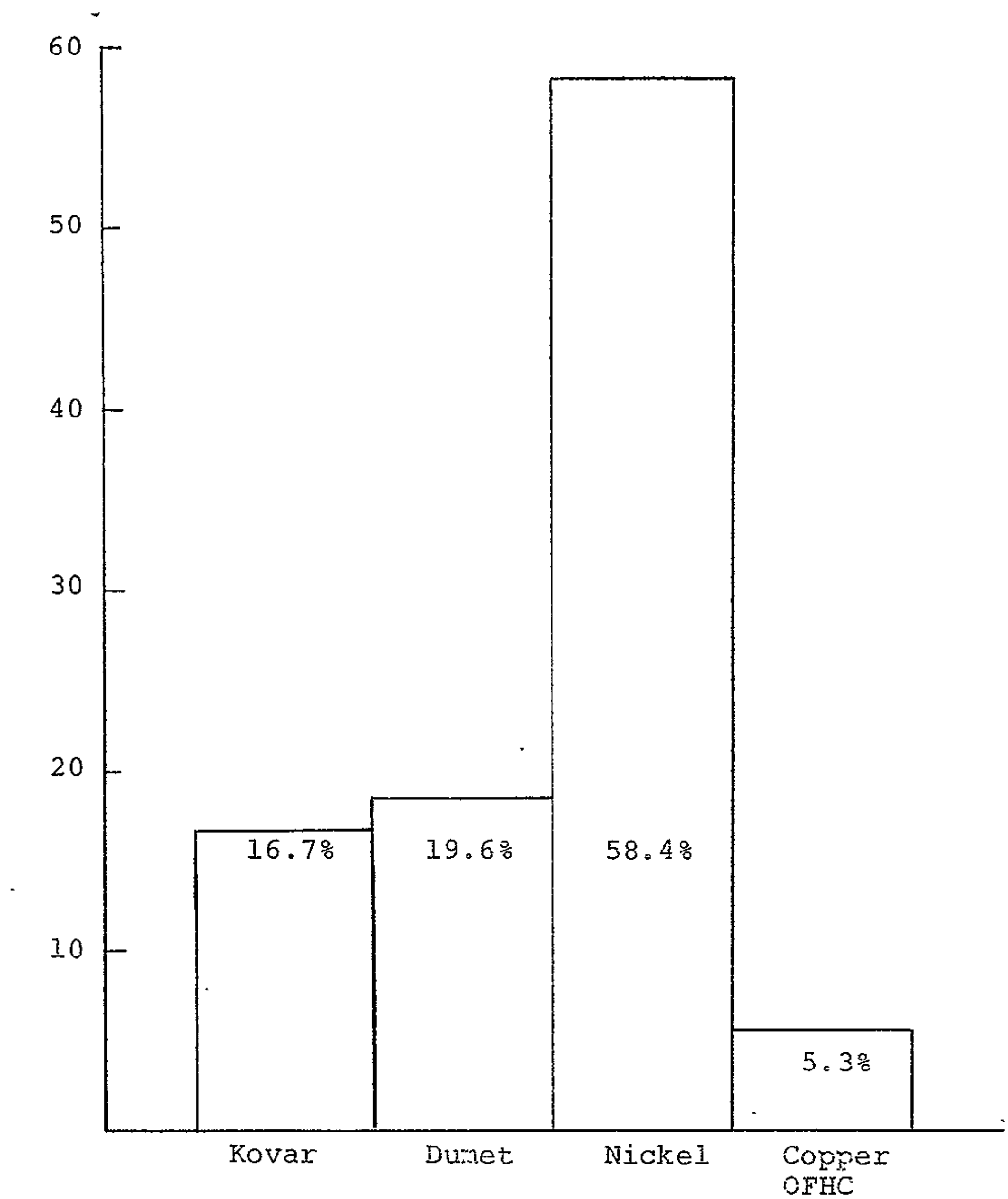
Material	Diameter	Force (lbs)	Watt-Seconds	Pulse Length
Dumet Au Flash	.025	6.0	5.4	Normal
Ni Au Flash	.020	6.0	5.6	"
Ni Au Flash	.025	6.0	6.5	"
Kovar Au Flash	.017	6.0	2.8	"
Ni Au Flash	.016	6.0	4.0	"

TABLE 2

MATERIALS USED IN NDT EVALUATION AT GD/P
.012" X .030" Nickel Ribbon Interconnect

Material	Diameter	Force (lbs)	Watt-Seconds	Pulse Length
Kover Au Flash	0.017	8.0	10	Long
Dumet Au Flash	0.020	8.0	14	"
Nickel	0.020	8.0	22	"
Nickel	0.025	8.0	28	"
OFHC Cu Sn Dipped	0.025	8.0	44	"

(See page 12 for discussion)



Distribution of Materials Used at

LMSC and GD/P

During NDT Testing

B. <u>Operator Reaction</u>

- <u>Acceptance</u> -- During the evaluation program seven different operators were utilized. Adaptation by the operators to the presence of the NDT system came about rapidly in each case. Initial objections concerning the "Big Brother" aspect of the system subsided after a brief exposure, and they began to take interest in the system.

- <u>Workmanship</u> -- The workmanship of each operator improved markedly. Since we had not anticipated this, we observed the NDT stations closely to determine the reason for improved workmanship. We found that the frequency of NO-GO indications quickly made the operator aware of which welds on any particular module were difficult to make. Usually this was due to the module layout. As a result, the operator took particular care in troublesome areas or changed her welding sequence such that the area became less critical to weld.

- <u>Interest</u> -- It was observed that the operator concentration on the job seemed to be enhanced by the presence of the system. Operators who utilized the station seemed to gain a new awareness of what they could do to increase the quality of their welds.

C. <u>Station Operation</u>

- <u>Output</u> -- At no time was the NDT station output less than that of the other weld stations on the line. In most instances the NDT station module output was larger than those of other stations. This may be due in part to the increased concentration the NDT station operators displayed.

- <u>Maintenance</u> -- In order to dress and adjust the electrodes, the operator first moved the IR transducer to the fully-elevated position. She then proceeded to dress and adjust the electrodes in a normal manner. Upon completion of the operation, the transducer was lowered against the keyed stop to its original position and clamped as provided for in the transducer design.

Periodically during the evaluation it became necessary to replace the welder electrodes. This operation required the IR transducer to be elevated and the weld pulse channel pickup leads to be removed. This operation required about 15 seconds to execute. Reversing the operation required a similar amount of time. Thus the total interference time generated by the presence of the NDT transducer assembly is in the order of thirty seconds per maintenance operation.

D. Defective Weld Detection Effectivity

As may be expected from well-controlled welding operations such as the ones in effect at the participating organizations, the actual bad welds produced represented a small proportion of the total welds fabricated. However, numerically a significant amount did occur. Considering that it takes only one weld failure in most instances to render a circuit inoperative, it is extremely important, from the standpoint of both cost and reliability, that defective welds be detected, and especially that they be detected at a point in the production cycle where repairs can be made.

The following is a summary of the results of the NDT prototype evaluation program as observed at LMSC and

GD/P. In order to evaluate these results properly, however, it is first essential that the following factors be recognized and considered.

1. Normal user production visual inspection and process controls were exercised concurrently with the NDT evaluation. In each case where the NDT results did not agree with visual inspection the questionable welds were reinspected by the user and WVS. In the final analysis it was the user inspector who determined the acceptability of questionable welds. Their decisions were based on qualitative assessments of the weld strength as determined by applying a force to the joint, by means of a scribe or orange stick. If the weld survived without separation of materials or other damage, it was generally accepted regardless of its cosmetic appearance.

2. Since the evaluation program involved actual production hardware, it was obviously impractical to verify the actual pull strengths realized in either accepted or rejected welds by means of destructive pull tests other than on a sample basis for purposes of system calibration.

3. The acceptance limits programmed into the NDT systems were selected to ensure that all accepted welds would exhibit a joint pull strength at, or above, the lower 3σ limit as derived from the weld schedule information. Thus, the implication of a rejected weld is *not* that it will necessarily exhibit *zero* weld strength, but rather that it is a *substandard weld*.

E. Summary of Results for 33,000 Production Welds

No defective welds were accepted by the NDT systems in either facility.

Throughout the entire evaluation program, the prototype systems did not accept any welds which were later determined, either by visual inspection or subsequent electrical test, to be defective. This conclusion was verified by tracking all of the modules, welded on the NDT systems, through pre-pot and post-pot functional electrical tests.

162 bad welds detected and confirmed by user visual inspection.

These welds were rejected by the NDT systems and in the normal process of visual inspection were also rejected. The visual inspection was done remotely from the NDT stations and the inspectors had no prior knowledge of the NDT results.

210 degraded welds detected by NDT systems.

These welds were rejected by the NDT systems but accepted by user visual inspection. The welds were subsequently reinspected by both WVS and the user QA inspectors and could not be positively classified as "clearly defective" (i.e., "zero-strength welds") on the basis of visual inspection alone. Since these were production units, the users were understandably unwilling to permit destructive pull tests to be performed on the questioned welds and these units were subsequently passed on a "use as is basis." However, the fact is that the measured weld attributes did not fall within the established acceptance limits and therefore were flagged as substandard by the

NDT equipment. In effect, the system was unable to *confirm* them as being *good*.

Operator errors prime cause of defective welds.

Operator errors were, not surprisingly, the prime cause of defective welds. In descending order of importance they were: mispositioning of work between the electrodes, failure to select the correct welding schedule, failure to select any energy at all, and incorrect force settings.

Process control effectiveness demonstrated

Potentially serious process control deviations actually occurred during the production evaluation phase. Since these are not reflected in any previous discussion, they are noted below:

- <u>Improper setup</u> -- Ten consecutive welds were rejected immediately after routine station maintenance by the user. Examination of the setup showed that the electrodes had been improperly dressed and were set out-of-alignment. Redressing and adjusting the electrodes corrected the condition.

- <u>Energy drift</u> -- A series of Dumet welds was rejected by the NDT system (IR-Lo, SD-Lo). An examination of the setup showed that the welds were being made at 12.5 watt-seconds instead of 13 watt-seconds. The situation was corrected and normal welding resumed.

- <u>Contaminated lead material</u> -- This problem occurred most frequently in Kovar lead materials. The contaminant in each case was clear varnish or epoxy, and difficult or impossible to detect visually. In the case of Kovar to nickel ribbon welds (10 watt-seconds), the problem would genera-ly be apparent to the operator with or without the NDT indication (Weld Pulse-Hi, Setdown-Lo), since an audible crack would usually be heard. However, for the case of Kovar to nickel wire welds, where the energy requirement is considerably less (2.8 watt-seconds), the no-weld condition was not always obvious, and in these cases the NDT system rendered the problem apparent and initiated prompt remedial action.

- <u>Wrong pulse width selection</u> -- The Weldmatic 1-065 power supplies have three selections of output pulse duration. The discharge times for an energy setting of 50 watt-seconds are, "Standard," 2.1 ms; "Normal," 3.5 ms; and "Long," 7.8 ms. Since the energy storage voltage on the welding capacitor is the same for any given watt-second setting, the peak energy delivered to the electrodes is inversely proportional to the discharge times. For example, the peak voltage developed across a 150 micro-ohm shunt at 14 watt-seconds "Normal" pulse is 0.3 volts; for the same energy and "Long" pulse the voltage is 0.2 volts.

  The great majority of nickel ribbon welds were done on the "Long" pulse setting. Occasionally, though, welds were made that required a "Normal" pulse.

Additionally, at one facility, the Weldmatic power supplies were checked daily by means of a Raytheon Weld Calibrator which also worked from a "Normal" pulse. On all occasions where the pulse width was incorrectly selected the NDT systems refused to accept the weld.

III. CONCLUSIONS

Based upon the results obtained both in the laboratory and during the production evaluation portion of the program, this NDT system offers significant possibilities for achieving improved reliability and reduced costs in the fabrication of welded electronics assemblies. Specifically:

- NDT system determines weld quality accurately. With properly established acceptance limits, all welds accepted by the system can, with a high degree of confidence, be considered "good" by the user without the need of subsequent inspection.

- Inspection costs and the need for visual inspection can be substantially reduced. For example, in a typical production evaluation program, visual inspection would have actually been necessary on only 372 out of a total of over 33,000 welds. In addition, *each specific* weld that *requires* inspection is identified by the system which eliminates the possibility that it will be *overlooked* by the inspector.

- Defective hardware is identified earlier in the production cycle, thus maximizing the possibility of repair and leading to a reduction in "scrap rate."

- Experience during the evaluation program indicates that the system leads to a significant improvement in workmanship without adversely affecting production rates.

The NDT data application to process control has a significant advantage over the traditional periodic pull test coupon methods of control. This advantage lies in the fact that *the NDT data can be made available for process control evaluation at any time during a production run,* under actual production operating conditions, and without any interruption to the production. The sensitivity of the system's detection capability spans the range from subtle degradations in the welding machine to poor operator techniques, including detection of missed welds.

PART TWO

POSSIBLE APPLICATIONS OF NONDESTRUCTIVE TESTING TO MICROJOINTS

POSSIBLE APPLICATIONS TO NON-DESTRUCTIVE TESTING OF MICROJOINTS

The conversion of electronic circuitry from discrete components to monolithic and hybrid type integrated circuits poses interconnection problems similar to those explored in detail in this wire-welding study. It is still necessary to form highly reliable electrical connections between circuit chips and substrates, from substrates to the external package terminals and, at times, between adjacent circuit chips.

The integrity of these connections, or "microjoints," continues to be a major reliability problem, and in our opinion may ultimately impose the upper reliability limit of integrated circuits. As a consequence, a technique for nondestructively testing these connections is as important here as in welded module assembly, and was therefore the subject of preliminary studies during the final phase of this contract.

Fundamentally, the techniques employed in this program for the evaluation of wire welds are generally applicable to spot welding procedures where the area of metal joining is immediately under the movable electrode. The practical ability to extend these measurements of infrared energy, dynamic setdown, and weld voltage to the domain of microcircuitry is primarily a function of the physical geometry of the connection being made and the sensitivities needed to measure the three parameters which we have determined to be the best indicators of weld strength.

In an effort to make a preliminary judgment of practicality of applying these techniques, a comprehensive review was made of the types of connections and packaging being used today in the microelectronics field. The results of this study are presented in detail in Appendix A and are summarized in the following five paragraphs.

1. IC's are currently produced with aluminum metallization. Pads approximately 4 mils square are provided for external connection. Connections are made to these pads by either thermocompression bonding with gold and aluminum wire or by ultrasonic bonding of aluminum wire. This is the system which has been in service and has experienced limited reliability due to such things as purple plague, wide variability in joint strength and reduction in lead-wire strength caused by the bonding process.

2. IC's and discrete devices with aluminum metallization are being produced having aluminum projections in the pads -- or "bumps" -- for mating with pads located on the package substrate. Bonding is accomplished by ultrasonic methods using special optics in the bonding apparatus for exact positioning of the die on the substrate. Even though the finished joints cannot be viewed, the organizations using this technique report much higher system reliability. This method, along with others to be described, reduces significantly the number of bonds required.

3. A variation to aluminum projections on the die as described in 2 above is the scheme where projections are provided on the aluminum substrate to mate with the die. The system behaves quite like 2, but is aimed at using die that are not specially prepared. This system also requires ultrasonic bonding methods. The reliability improvements are not as good as in 2, perhaps because of a larger variety of IC makers involved.

4. Face bonding with solder has been employed by IBM in their S.L.T. (Solid Logic Technology) (App. A; paragraph C) computer systems. Very high joint reliability has been achieved according to their reports. The system employs depressions in the pad areas of the IC which are subsequently filled with solder-coated copper balls. The termination of the circuit is made by face down positioning of the die over solder-coated pads and reflowing the solder. Surface tension of the solder provides excellent connections even with slight surface irregularities. The system is not inspectable after bonding.

5. Face bonding with beam leads is the most likely new system for interconnection, since it possesses many improvements desirable in IC reliability, including bond reliability. There are variations to beam lead techniques, some described later, but for the purpose of NDT potential the beam lead technology is that introduced by Bell Labs. The technique uses titanium and platinum over the silicon, with gold electroplated on top as the integral interconnect beam. Insofar as external joining is concerned, the beam lead is pure electrodeposited gold. The process also provides SI_3NO_4 insulation over the chip, providing a superior hermetic seal around the pad and over the surface. This beam extends beyond the edge of the circuit die and serves as a tab that can be welded or otherwise bonded.

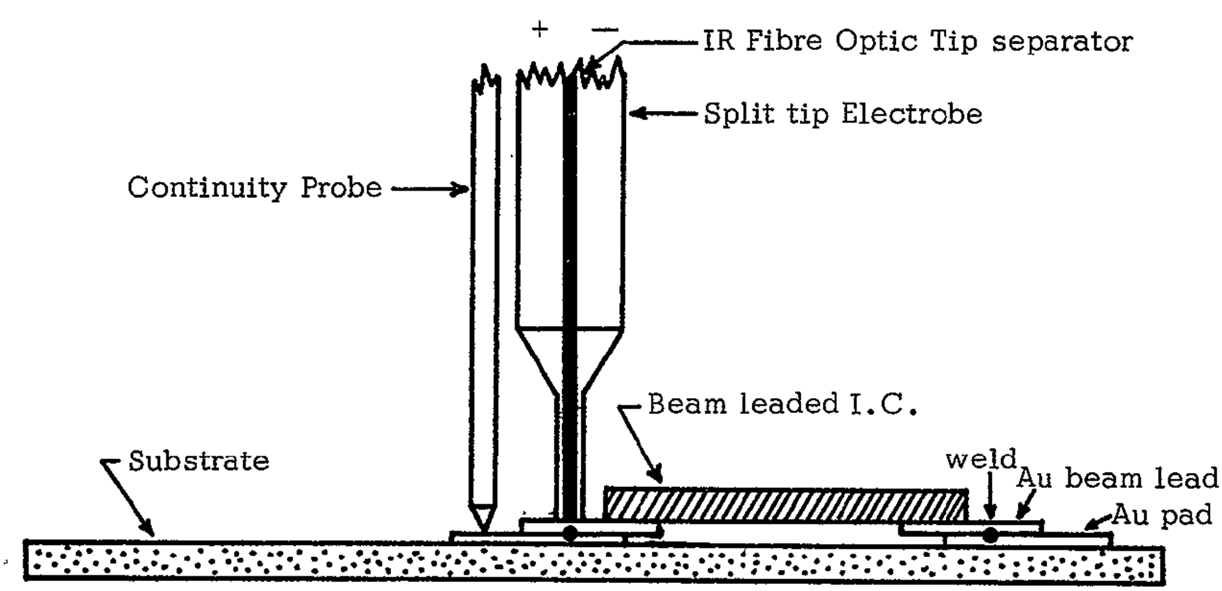
Joining methods which have been proven for these beam leads are (1) thermocompression bonding, (2) ultrasonic bonding, and (3) resistance welding.

B. Immediate Application of NDT Microcircuits

With the inherent advantages of beam lead techniques, we believe that more attention than ever will be focused on joint reliability, particularly for those cases where the maximum possible reliability is required. Programs where human life is involved or where deep space missions cannot be lost deserve special efforts to measure each joint for acceptance and for these cases initially the extension of the WVS NDT system is justified. It is our belief that the WVS NDT system can be immediately extended to the beam lead joint when the joint is made one at a time, as is the case where joining with a parallel gap microwelder (see Ref. 12). NDT data for joint qualification will have to be obtained by instrumenting the welder, as was done in our earlier work. Data needed are:

(1) setdown, (2) peak weld current, (3) peak IR at the weld zone.

Also required may be an additional assurance of good metal-to-metal interface by measuring continuity prior to welding (weld energy would be withheld if the conductivity was insufficient). Development effort is needed to obtain increased sensitivities for smaller setdown differential (approx .0001 vs. approx. .0002). Present transducer sensitivity is 3.5 mv per mil. and it may be directly usable. For IR sensing across 4 mils in a band approximately 1 mil wide, fibre optics might be employed. No problems are anticipated in obtaining peak weld pulse current and interface continuity. The IR measurements would likely be more accurate than with crosswire welding because of the precision location and the restricted material combinations. However, we anticipate a lower IR output requiring more sensitivity. The welding system may require the added continuity measurement because the weld energy is applied to one piece only across the parallel gap, as shown below.



C. The NDT techniques which we have developed for large cross-wire welding (ranging from .016 dia. to .045 dia.) may be applicable to the following additional bonding systems with a scaling down of sizes of leads (ranging from .0004 X .0025 to .0006 to .0045). These two bonding systems are:

1. Thermocompression bonding of Gold Wire to Aluminum Pads
2. Thermocompression bonding of Gold Wire to Gold Pads

D. The NDT system developed for large cross-wire welding is not directly applicable without major changes in instrumentation concepts to the following types of microbonding:

1. Ultrasonic bonding of all types of connections and packaging
2. Microsoldering of all types of connections and packaging

E. The anticipated trends for microbonding are:

1. Some microgap welding of gold beam leads will be employed, but to a limited extent. The NDT techniques are directly applicable except for size scaling. [Ref. 12, 20]
2. Gold beam-lead terminations will be used to a large extent and these will probably be joined on a mass-production basis by a heated-wedge thermocompression "wobble" motion bonder. The NDT microweld system may be applicable with modification

of instrumentation and parameters. [Ref. 4,5, 7,8]

3. Ultrasonic joining of beam leads. The NDT micro-weld system is not directly applicable and would require major conceptual changes.

F. There is a lack of concern in the industry for precisely measuring joint-by-joint quality even with the knowledge that present IC failures exhibit joint failures as a primary cause of IC failures. [Ref. 19] A typical failure rate expected on IC's is .001%/M hrs, or a MTBF of 100,000,000 hrs. [Ref. 25] This <u>very</u> low rate of failure is incompatible with current methods of inspection on the joint, where approximately 1-5% of the "bad" joints is removed by environmental testing subsequent to device packaging, but certain of the remaining marginal joints are delivered to the end product undetected.

G. A more rigorous set of <u>bond strength standards</u> is needed for the industry. Our work with NDT weld joint acceptability demonstrated that reliance on statistical methods can be grossly in error, particularly about the probability estimates in the lower tail of the distribution function. The new Microelectronic Specification, MIL-M-38510, requires demonstration of bond integrity and provides for bond strength test methods, but leaves the strength requirements to applicable procurement documents. [p. 3.7 MIL-STD-883] Within the Electronics Industry there is much controversy on the wirebonding requirements of MIL-STD-883 [Ref. 27]. We believe that there is adequate technical knowledge about bonding processes and equipment to permit an absolute basis for bond strength requirements, and that these requirements could be developed and added to MIL-STD-883 [17E].

APPENDIX A

DETAILED DISCUSSION OF BONDING METHODS AND BASIC METALLIC SYSTEMS USED

I. BONDING METHODS

There are three basic methods of joining currently being employed -- Thermocompression Bonding, Ultrasonic Bonding, and Microsoldering. To determine the applicability of the NDT system to each of these bonding methods requires further definitions of the packaging methods and the metal systems used. The parameters of critical interest which should be monitored for nondestructive test data are enumerated for each with the most critical listed first.

A. Thermocompression Bonding

Thermocompression bonding parameters to be monitored for NDT instrumentation are:

1. Interfacing metal temperature during bonding
2. Time duration of bonding temperature and pressure
3. Pressure of surface-to-surface contact during bonding
4. Surface area in contact during bonding
5. Atmosphere surrounding bond throughout bonding operation
6. Surface cleanliness

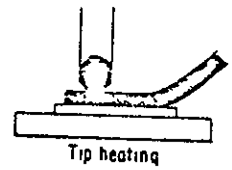
Thermocompression bonding is effected by many techniques which will have an effect on how the NDT method is implemented. Each of these methods can employ substrate heating alone, tip heating alone, or both substrate and tip heating together. Four general classes of thermocompression bonding are described in the following discussion.

1. Wedge
2. Ball (nailhead)
3. Stitch
4. Microgap

"The work of O. L. Anderson and H. Christensen, both of Bell Telephone Laboratories, in the discovery and development of thermocompression bonding is well recognized. Thermocompression bonding is the joining of solid materials to each other by the application of heat and pressure to create plastic deformation and intimate contact between the solids over as large a portion of the apparent area as possible. The process is extremely critical in requiring ultracleanliness, fully annealed wire, and precise operating conditions. In essence, 'white room' conditions give the best results. An inert atmosphere also contributes greatly to reproducibility and reliability by reducing oxidation contamination during heating. To produce bonds of high strength and low variability, the materials should be at a temperature in the plastic range.

"Of the many metals tested, aluminum gives one of the highest bond strengths, when bonded to any other metal. Gold, with high chemical stability, is now the most frequently used material for thermocompression bonding and gives excellent results. Commercial equipment is available and consists of a heating mechanism, a bonding tip, and various mechanical arrangements to facilitate positioning and operation of the bonder."

Wedge. Generally, heating is applied to the wedge or tip. The base is often heated. The base may be heated without the tip being heated. The variables controlled here are (1) elements heated temperature(s) (tip base, or both), (2) time, (3) force, and (4) wire and film properties.



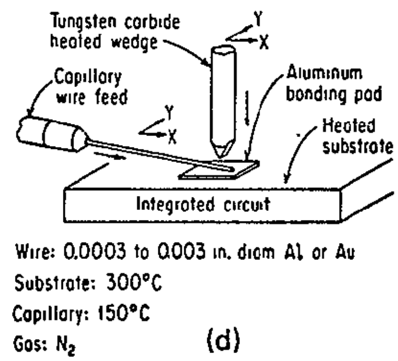
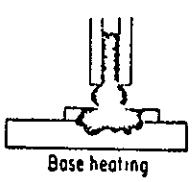


Fig. 1

(d)

Chisel or wedge bonding.

Ball or Scissor. Ball bonding employs a glass (or tungsten carbide) capillary through which the



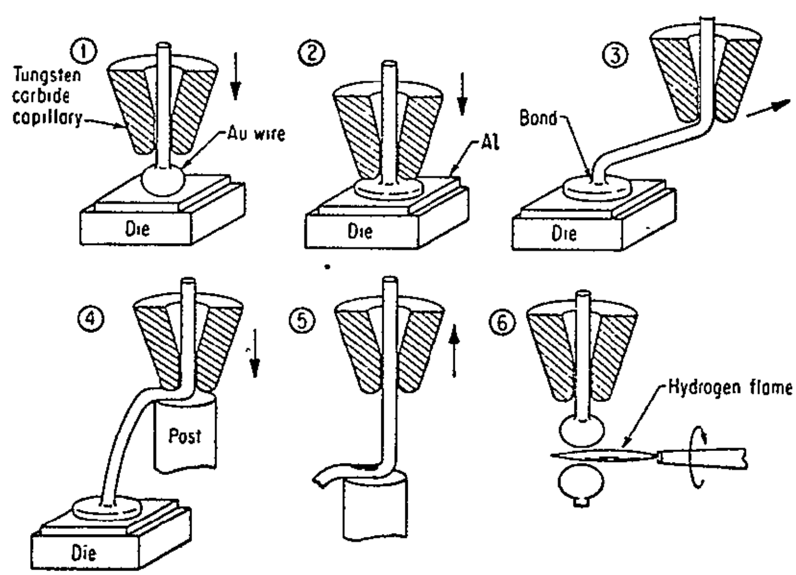


Figure 2.

wire passes, Figure 2. The ball is formed by a hydrogen gas flame cutoff operation which fuses a ball on both ends of the severed wire. The ball on the glass (or tungsten carbide) capillary is larger in diameter by at least two times, and the capillary transmits the force of joining against the ball. The substrate or base is heated.

Stitch Bonding. A variation in this form of bonding substitutes mechanical cutting for flame

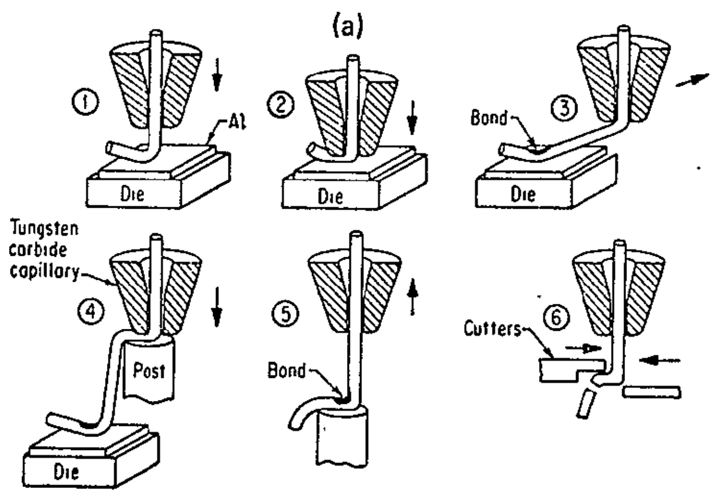


Figure 3.

cutting as is shown in Figure 3. This method is particularly applicable where ball formation is not feasible or desirable. The welding parameters are (1) base temperature, (2) force, (3) time, and (4) wire and film properties. [Ref. 1,18]

Microgap Bonding.

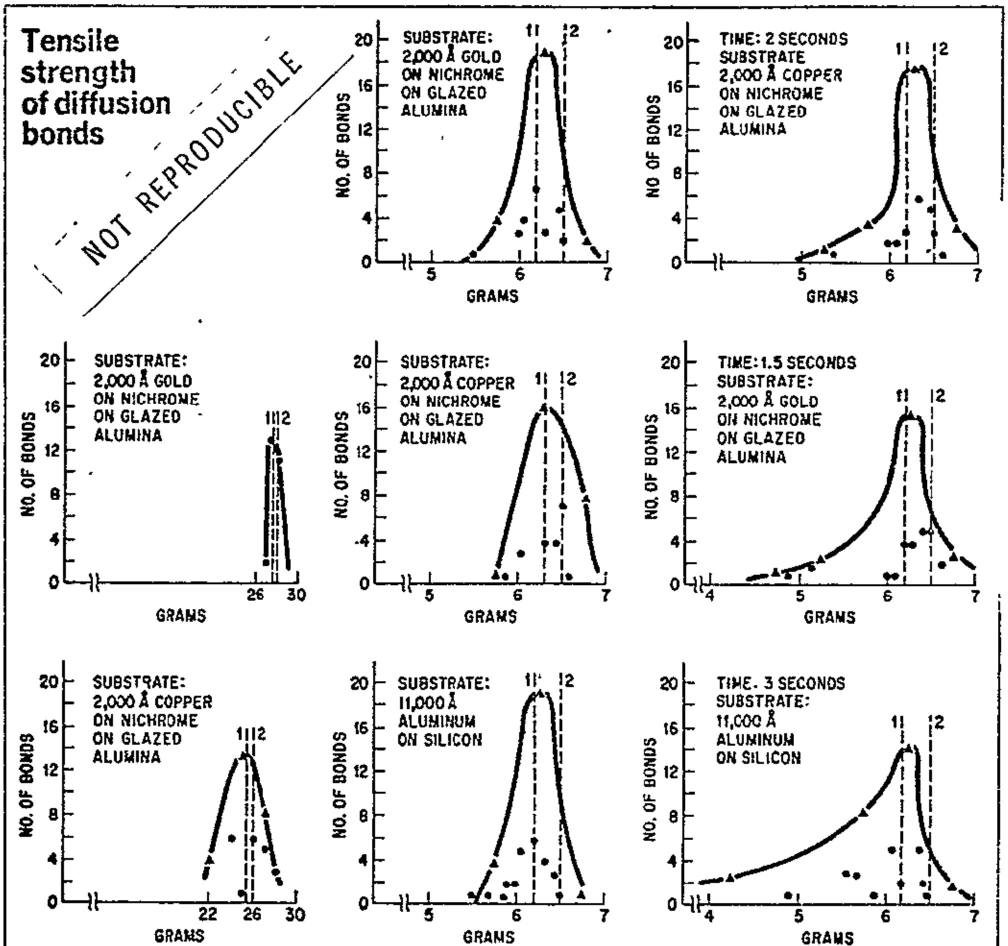
"A variation of standard thermocompression equipment, referred to as 'cold current bonding,' has the usual pressure tip wedge but a separate current supplier to provide a means of resistance heating the wire to the required temperature. Because the heating is localized in this setup, chances of overheating the semiconductor element are minimized.

"A most recent development has been the parallel gap welder, which can also be used as a thermocompression bonder by regulating the current applied. Its design features what appears to be a single electrode but what is actually t-o electrodes separated by an insulating material and powered by a standard resistance or capacitor discharge welder power supply." [Ref. 2]

Considerable investigation into the distributions resulting from several methods of thermocompression bonding by resistance heating was performed by Autonetics [Ref. 20]. It is seen (Figure 4) that the best distributions occur with microgap bonding. This microgap welding is the technique that most nearly approximates the larger crosswire welding method which was successfully implemented for NDT by WVS and which therefore has a high probability of early success for NDT qualification of microbonds.

B. Ultrasonic Bonding

In ultrasonic welding, components to be joined are clamped together between a welding tip and a supporting member or anvil, with only sufficient static pressure



Microgap bonding

45° tensile-strength tests
Wire: 2-mil gold, original tensile strength 28 or 26 grams
Bonding conditions, gold film
Pulse amplitude: 40-80 80
Pulse time, msec: 2-3-2
Pressure: 200 grams
Bonding conditions, copper film
Pulse amplitude: 20-62-20
Pulse time, msec: 0-3-0
Pressure: 250 grams
Electrodes: 15 (molybdenum)
1. Average breaking strength of bonds in grams
2. Average breaking strength of wire in grams
● Individual test data (gold to nearest 0.1 gram, copper to nearest gram)
▲ Grouped data in 2-gram increments

Resistance-heated wedge bonding

45° tensile-strength tests
Wire: 1-mil gold, original tensile strength 6.5 grams
Bonding Conditions
Force. 50 grams
Time 6 seconds
Temp: 482° C (capillary)
1. Average breaking strength of bond in grams
2. Average breaking strength of wire in grams
● Individual test data to nearest 0.1 gram
▲ Grouped data in 0 5 gram increments-

Pulse-heated wedge bonding

45° tensile-strength tests
Wire: 1-mil gold, original tensile strength 6.5 grams
Bonding conditions
Force. 50 grams
Time: see curve
Voltage: 1.99 v
1. Average breaking strength of bond in grams
2. Average breaking strength of wire in grams
● Individual test data to nearest 0.1 gram
▲ Grouped data in 0.5 gram increments All failures occurred in the wires

[Ref. 20]

Figure 4.

to hold them in intimate contact. High frequency vibratory energy is transmitted to the joint through the tip for a brief interval. Thus high-strength metallurgical bonds can be made in many similar and dissimilar metal combinations without applying external heat, without melting weld metal, without using fluxes or filler metal, and without passing electrical current through the joint. Many metal combinations are weldable by ultrasonic means which are not by other techniques [Ref. 1].

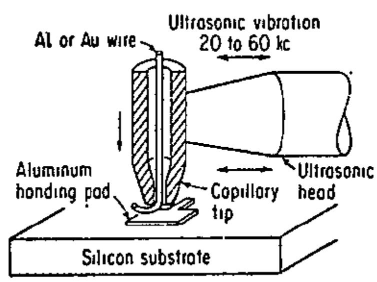
The critical ultrasonic bonding parameters to be monitored for NDT instrumentation are:

1. Energy
2. Transducer Frequency
3. Time
4. Transducer Excursion
5. Flatness of surface pad
6. Bonding tip parallelism to pad surface
7. Bonding tip shape

Some of these parameters are fixed by the ultrasonic equipment manufacturer such as frequency and excursion. There is some confusion in the industry about the use of ultrasonic bonding onto metal pads on silicon devices and there is concern about stresses on the silicon when ultrasonically bonding beam lead devices.

Western Electric Company reported work in ultrasonic wiring of microelectronic parts as early as 1965. At this time they stated:

"Ultrasonic welding is making rapid advances in the attaching of leads to semiconductors. The mechanism of ultrasonic welding greatly resembles that of thermocompression bonding insofar as it is the application of energy (ultrasonic instead of heat) to create intimate contact between the solids. However, ultrasonic bonding offers many additional advantages, such as the ability to join an almost unlimited range of similar or dissimilar metals, the lack of change of parent material properties, no contamination of weld area, ultracleanliness not essential, low ohmic resistance, low junction noise, and low joining temperature. Shown in Fig. 5 is a typical ultrasonic welder . . . ." [Ref. 2]



Ultrasonic bonding.

Figure 5.

Thus far, little information is available on methods of obtaining reliable bonds in hybrid circuits. One of the most critical factors found is the metallurgical specifications of the lead wire. For bonding leads directly to chips, the wire is 1.3 mils in diameter. Collins has found the most satisfactory wire for chip bonding to be 99.25% gold, 0.75% gallium. Small silicon trace is deemed very good. For 3 mil and larger wire 99.99% gold is used. Wire elongation should be 2% to 4%. Seemingly minor details such as the spooling of the wire stock can be critical. The addition of 1% silicon to aluminum wire improves its bond strength. Common cause of weak bonds is unevenness in height or flatness of the chip, or the use of devices from different manufacturers in the same hybrid circuit. The face of the bonding transducer's tip must be parallel to the chip face. Otherwise the bond will be made by one edge of the tip, rather than the entire face. This makes the bond area smaller and the concentration of bonding pressure can thin the wire excessively and may damage or fracture the chip surface. It has been found that the ultrasonic vibration during bonding degraded some devices. A type 2N2432 transistor application where low leakage current requirements existed (2 nano-amperes) had 3 out of 4 failures after bonding [Ref. 20].

C. Soldering

Several soldering methods are being used for joining in microelectronics.

1. SLT (Solid Logic Technology). Employed by IBM, this method uses glass-sealed chips and solder-coated copper balls or solder alone. The joint is "made" by reflowing the solder with the device face down on the substrate in position. IBM tests suggest that the method is as reliable as the conventional wire bonding.

2. Microsoldering can bond relatively large leads, .010" to .030" when employing cased miniature parts in a microcircuit. Many of the limitations of manual soldering can be overcome by dynamically-controlled resistance soldering and reflow methods.

But soldering cannot be used to bond thin gold leads .002" to .010" in diameter because molten solder dissolves the gold thereby weakening the joint. Microgap diffusion bonding--a cross between parallel gap welding and thermocompression bonding--can be used to bond these intermediate-sized leads. Both of these methods require close control, the thinnest lead .002 mils is 250 times as thick as a typical 2,000 Å thin film creating film adherence and solution problems. Heat input must be carefully controlled to prevent cracking of the thin-film substrate or dissolving of the conductor and subsequent dewetting. There may be excessive peel stresses at the joint, due to stresses applied to large rigid leads. The relatively large solder mass needed to connect large leads may also induce stresses due to differences in thermal coefficients of expansion. Furthermore, relatively large amounts of heat needed to melt the solder may degrade thin film components [Ref. 2]

3. <u>Indium-Copper Soldering</u>. An interesting two-phase soldering system has been developed by Signetics Corporation which overcomes some of the problems associated with soft soldering. Four particular bond requirements were met in the development program:

    a. Bonding yield must approach 100%.

    b. Chips must be removable and replaceable after testing the assembly.

    c. Assembly should withstand high temperatures for hermetic sealing of lids.

    d. Bonds must be reliable.

The process employs an aluminum substrate with gold and glaze crossovers followed by titanium copper interconnects. A chip with copper bumps on aluminum metallization is face-bonded to the substrate. The bumps are indium covered. An initial indium solder bond can be formed to permit electrical test. The final bond formed at 450°C is an alloy of indium and copper. This system meets the four requirements above and in addition is low in cost. A study of the copper aluminum interface indicates that interposing an additional barrier layer of platinum to avoid Al-Cu interdiffusion appears to be unnecessary for most conditions, but will be desirable as a safety factor for high temperature lid sealing. [Ref. 17d]

The critical parameters for monitoring soldering are complex and present a different NDT instrumentation development, but generally they are as follows:

1. Prior to soldering

    a. Solderability of mating surfaces
    b. Solder metal constituents
    c. Flux condition

2. During soldering

    a. Temperature
    b. Time
    c. Temperature gradient rise and cool
    d. Disturbance-free solidification
    e. Dross inhibition
    f. Gravity effects
    g. Flux drying

II. METAL SYSTEMS

Applicability of nondestructive testing techniques to future microbonds is dependent upon the metal systems being joined. The metal systems which are being used must be compatible with active silicon devices and in addition must have the potential of sound metallurgical joints without undesirable intermetallics. The following metal systems were examined from which it was concluded that the most likely future metal system is the beam lead configuration developed by Bell Laboratories where gold is deposited over titanium and platinum in a batch-processing system as part of IC manufacturing. [Ref. 21] This prediction is made because there are problems associated with aluminum metallization which can be overcome by the gold system and flying lead wiring is also eliminated. The current problems which were part of the wire bonding technique are: more joints than necessary and relatively low joint strength. These two major problems are inherently eliminated with beam lead interconnecting techniques. Ideally, a single metal should be used for microjoining (at the device level) to avoid potentially troublesome intermetallic compounds; however, no single metal system exists which has the required properties. The gold beam may, however, be sufficiently pure away from silicon to be free of bonding intermetallics. Aluminum-to-aluminum has been widely used and has limitations which led to the development of the Gold Beam lead system.

A. Aluminum Wire to Aluminum Pad

Aluminum metallization on silicon has been used extensively and will continue to be the major method in use for some years. However, it has technical limitations which will force its replacement when a superior system is developed. The arguments appearing in the technical literature clearly show the trend.

A considerable amount of work has been done on the aluminum metallization system, with results which indicate various types of reliability limitations. Other metallization systems have been studied less extensively for IC applications. Consequently, they have less reported reliability limitations, and so are sometimes assumed to be superior.

The limitations of aluminum have been defined to a large extent, and are reasonably well understood. With this knowledge it is now possible to modify processes, device structures and designs, and to make use of appropriate in-process controls and screening tests to obtain significant improvements, both in manufacturing costs (due to higher yields) and in reliability.

It is concluded that aluminum will continue to be the most widely used metallization material, not only for single-level metallized IC's but also for multilevel LSI arrays. Processing and structural design improvements and more sophisticated process controls will permit significant improvements to be made in metallization-related performance and reliability of aluminum metallized silicon IC's. [Ref. 17a]

Two failure modes for silicon devices and IC's utilizing aluminum metallization are apparent. For typical small conductor geometries, failures due to this process become important (lifetime less than 10 years) at current densities exceeding 5×10^4 A/cm^2 and temperatures in excess of 150°C. It is also qualitatively apparent that a positive gradient (in terms of electron flow direction) of metal ion diffusivity in the conductor will establish a region where vacancies preferentially condense. Similar effects should be caused by positive gradients in current or temperature. The formation of etch pits into silicon has been shown qualitatively to occur under the influence of elevated temperature and high current density at Al-Si contacts where the electrons flow out of the silicon and into the aluminum or where the major component of electron flow is parallel to the Al-Si interface. Device failure can occur when an etch pit (filled by Al) grows across an underlying junction resulting in a short. [Ref. 17c]

B. Gold Wire to Aluminum Pad

The most thoroughly studied void forming region in semiconductor devices and integrated circuits is at the bond, particularly between the gold wire and the aluminum metalization. Here the rapid formation of the dark purple to black intermetallic compound $AuAl_2$, which along with other gold-aluminum intermetallic compounds produces a weak bond containing voids, has come to be known as purple plague. The purple plague becomes quite evident after an overnight bake at 300°C. Baking at 200°C requires a longer time to be as pronounced, namely 24 to 36 hours. The catalytic role played by silicon in accelerating the aluminum-gold compound may be found described elsewhere. [Ref. 1] Careful examination of gold aluminum bonds has revealed the presence of a number of intermetallic phases in the bond. Furthermore, the presence of voids in the gold or gold-rich metallic has been reported. These intermetallic phases form at both gold-aluminum bonds, but much more rapidly at the semiconductor bond because of the accelerating role played by silicon. [Ref. 17f]

The compound-forming potential in a binary metal system will ultimately cause a solid state diffusion controlled reaction to occur. The extent of the resulting compound formation is proportional to the temperature and the time. It may be that all of the possible compounds for a system will ultimately be found, because of the concentration gradient across the systems. This occurs, for example, in the AlAu system where all of the five possible compounds are found. Diffusion of the two reacting metals will proceed, but at rates which are limited, not by the anneal temperature, but also by the diffusion of each metal through the bonding layer of intermetallic compounds.

Since these rates may be expected to be different, diffusion rate discrepancy will cause a vacancy buildup which will condense to produce voids. This will result in bond weakness and eventual opening. [Ref. 17f]

A number of metallization interconnect bond systems for monolithic IC's have been developed or are in active development. Every one of these systems involves the potential formation of other intermetallic compounds. [Ref. 17f] Some of these systems are:

1. Aluminum Metallization, Chromium Overlay, Gold-Wire Bond
2. Aluminum Metallization, Titanium, then Gold Overlay, Gold-Wire Bond
3. Molybdenum Metallization, Gold Overlay, Gold Wire Bond
4. Platinum Contact Titanium, followed by Platinum and Gold Overlay - Gold Wire Bond
5. Chromium Metallization, Silver Gold Overlay, Gold Wire Bond

C. Gold Wire to Gold Pad

This metal combination is ideal since there are no intermetallic compounds which complicate the joint characteristics. Gold as a material is the easiest to join since there are no oxides or compounds formed on the surfaces. Gold can be joined best by any of the thermocompression methods including cold forming. Gold cannot be used in direct contact with silicon as an ohmic contact because it dissolves interstitially into silicon which changes the semiconductor performance. For these two reasons, an interface is used to make ohmic contact with silicon and to provide the desired adhesion. Pure gold joints away from the silicon are desired if the gold wire itself has adequate strength.

D. Aluminum Beam Lead to Aluminum Pad

This single metal combination is free of unknown or undesired intermetallics and is therefore potentially very reliable. Aluminum pads on silicon are the most frequently used and are well understood. This metal system can be joined by ultrasonics and by thermocompression bonding with high reliability. Aluminum is, however, a very active metal which can be seriously degraded by dissolution in the presence of moisture or electromigration at high current densities (see A above).

E. Aluminum Beam Lead to Gold Pad

Several companies are experimenting with devices having aluminum beam leads with the intention of end item protection in vacuum to avoid degradation by moisture. The foregoing discussions relative to aluminum metallization (A and D) are applicable for this combination and in addition the problems of gold aluminum intermetallics suggest that this combination will be avoided. The bonding of these two metals is achievable by thermocompression bonding and ultrasonic methods.

F. Gold Beam Lead to Gold Pad

The single metal system of gold is the ideal joint being sought since gold bonds to gold easily and gaseous contamination of gold does not take place. Unfortunately, on silicon IC's direct contact of gold is not workable and in addition the limitation in gold beam physical strength is of concern at the .002" X .0005" dimension for IC and transistor chips. When sufficient cross section can be obtained for joints away from silicon, the all-gold system should be used. Gold is most easily joined by thermocompression bonding.

G. Multimetal Gold Beams to Single Metal Gold Pads

In the search for a metallization system to replace aluminum it is apparent that no single layer material conveniently satisfies all the necessary requirements. Systems which consist of a refractory metal followed by a noble metal which acts as a main conductor are the current best method. Within this framework the Cr-Au and Ti-Au could have limited usefulness on Si IC's due to metal-to-metal reactions and attendant resistance changes at device processing temperatures. The systems Ti-Pt-Au, Mo-Au, and W-Au have been shown to be thermally stable for extended times at 450°C and compatible with Si devices. Furthermore, the gold-based systems have been shown to permit longer lifetime operation at high current densities than Al thin films.

The technology for these composite films is much more complex than that for aluminum and can, in itself, if not properly controlled, introduce new failure modes. However, their improved characteristics with respect to non-penetration of shallow junction devices, resistance to deterioration in adverse environments and greatly increased current carrying capability, makes their usage an attractive possibility on integrated circuits (and devices) that have severe design requirements or intended operating conditions. [Ref. 17b]

Beam Leads with Pt Contact Ti + Pt and Au over bonded to a gold pad is a complex system intentionally forming one of three possible Pt Si intermetallic compound PL_5Si_2. However, investigations by X-ray diffraction have shown that compound rearrangement also occurs to produce Pt Si, which further undergoes rearrangement to a layered structure. In addition to the several different intermetallic compounds which can and do form between Pt and Si, three Ti-Si intermetallic compounds, four Ti-Pt intermetallic compounds, and four Ti-Au intermetallic compounds are reported. Catastrophic failures in this system are obtained when any of these overlay metals breaks through to the silicon, presumably involving compound-forming reactions. Insofar as bonding is concerned, the multimetal system is only of concern if the gold beam is contaminated due to prior processing steps. The behavior should be exactly like the monometal gold system sought for best joint physics. [Ref. 17f]

III. PACKAGING

The accessibility for implementing NDT monitoring is dependent to a large extent on the packaging method. The various packaging systems which are being developed or used today are described and detail the following methods:

A. Flip Chips

B. Plastic Structured Microelectronics

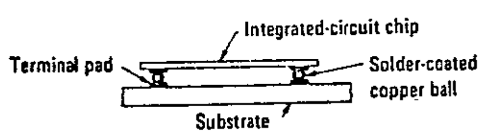
C. Beam Lead Packaging

The packaging of electronics begins when the die is attached to the package and is first connected to the outside world. Even though the semiconductor wirebond is the primary cause of IC failure, it is still the highest reliability joint in the electronic system. This fact has created a "mad" scramble in the industry to simplify the interconnection system above the device packaging. A simultaneous effort is applied to make the first level (chip bonds) bonds of significantly higher reliability. As a consequence, a large variety of packaging schemes are emerging, particularly for subsystems, nominally referred to as hybrids. The packaging method should not be confused with a bonding method although the two subjects are inseparable. We believe that an all-beam lead system (a common housing for many beam lead devices) will eventually emerge as the optimum in reliability and cost; however, in the industry we are likely to experience a wide variety of chip techniques assembled in one package before the emergence of a uniform technology. Device packaging will be first to become settled because of a packaging requirement for only one part. A few of the packaging methods being used or introduced are discussed briefly.

A. "Flip Chips"

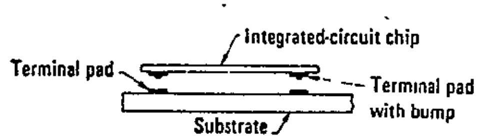
"Flip Chips" are face-bonded leadless parts, including but not limited to Diode Transistors and Integrated Circuits. This technique is used in packaging IC's as well as in an assembly of parts on a common substrate (hybrid design). Flip chips are used to avoid wire bonding and result in a reduction of the number of bonds in a system. (Many schemes are reported to be more reliable than wire bonding.)

1. Solder reflow of solder or solder-coated projections.



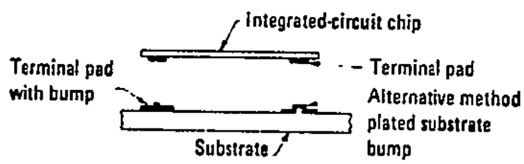
[Ref. 3]

2. Projections of aluminum on IC's to match coordinated terminal pads on the substrate. A large quantity of transistors and IC's are being used in industry which utilize this bonding method.

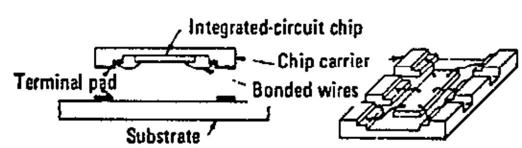


The extension of the aluminum metallization technology provides an easy transition and the appearance of bonding tools with special optics provide precision positioning which can be readily observed by the operator just prior to effecting the bond. Bonding is by ultrasonic or thermocompression methods. [Ref. 3]

3. Projections of aluminum to match the IC pattern on the substrate utilizing conventional IC's with aluminum pads. Bonding is by ultrasonic methods.

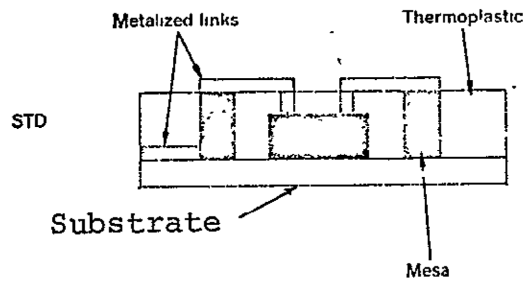


4. LID's (Leadless Inverted Devices). This form of packaging employs an intermediate carrier of insulating material to provide monitoring and wiring of the Integrated Circuit or other device chips. The completed LID can be independently tested and fully qualified prior to assembly into the subsystem. In the event of failure, independent LID's can be removed easily without disturbing the balance of the parts in the hybrid assembly. Bonding is leadless by mating pads on the LID and substrate. Bonding is by ultrasonic techniques.



B. <u>Plastic-Structured Microelectronics</u> [Ref. 13,15]

General Electric Company is developing a packaging method called STD (Semiconductor-Thermoplastic-Dielectric) where the chip is bonded onto a substrate in a conventional face-up position. The substrate is made with mesas to perform top surface links to the substrate. The assembly of all such parts



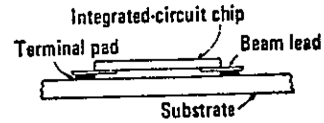
needed for a hybrid combination of a subsystem is completed and then followed by the application of an inert thermoplastic material. The plastic is then etched to expose the chip pads and substrate conductor pattern on the substrate. The system is then metallized over the thermoplastics which interconnects the chips. Hundreds of connections have been made simultaneously in the batch process described.

C. Beam Lead Packaging

The basic concept of beam lead assembly is the cantilevered continuance of a lead from either the monolithic device or from the interconnect matrix. In either case the system avoids flying wire connections by bonding the integral cantilever beam with a coordinated pad located on the mating part or matrix. The concept eliminates one of two necessary joints for each terminal, improving reliability by this factor alone. The geometry and metals used should improve the joint reliability when compared to a wire bond. There are several beam lead packaging methods being introduced.

1. Device Beam Lead [Ref. 21,22]

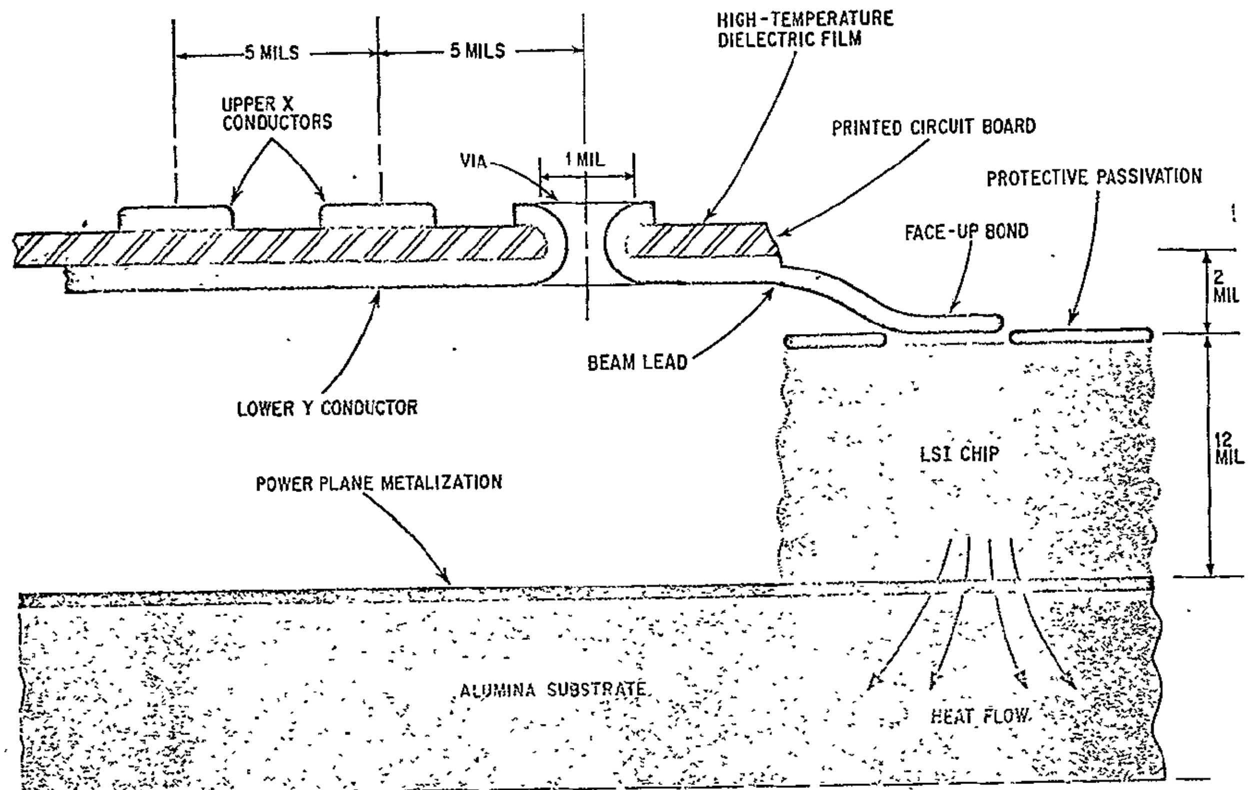
A substrate is utilized which has metallized pads which match the dimensions of each beam lead device. The device is located, face down over the pads, and then the leads are bonded--usually all at one time. The joints made are visually available after bonding and the removal and replacement of a faulty IC is reliable except that the IC removed is not reuseable. The beam leads are made as part of the device during its batch processing which avoids any bonding operations onto the silicon. Using beam lead sealed-junction technology, Bell Labs has constructed a 4096 bit memory array. This array utilized 64 chips, 50 mils X 60 mils, mounted on a 1.5" X 2" alumina substrate. Single level substrate metallization was adequate when runs were made to pass under the chips. Bell's experience with beam-lead technology indicates that cost and reliability are not critically dependent upon the number of beam lead interconnections. [Ref. 24c]



Beam lead bonding.

2. Matrix Beam Leads

Motorola Semiconductor Products, Inc. has developed a packaging method which they call beam-lead laminate. In this process cantilevered beams are integrally constructed with the conductor wiring pattern on a two-layer printed circuit matrix. The IC chips are bonded face up to the matrix by ultrasonic bonding techniques. As is shown in the following figure, the two-layer matrix has openings which accommodate the IC's which are lead-bonded prior to die bonding to the alumina substrate. The assembly can be tested and defects replaced prior to final assembly. The die bonding step also includes matrix-to-substrate bonding for ground connection. This system has thermal advantages over other beam lead packaging since the thermal resistance is lower by die-bonding than by lead connection.



Cross-section. In one electroplating cycle, the beam leads are integrally formed with the upper and lower conductors and anchored by means of the vias. The beam lead, which contains a 2-mil offset for strain relief, is bonded face-up to the LSI chip. Thermal conductivity is through the alumina substrate base rather than the contacts. Power is delivered to the chip by a metalization layer on the substrate.

[Ref. 11]

3. Rigid and Non-Rigid Beam Lead Substrates

Beam lead substrates provide a second level interconnection system which can accommodate either beam leaded devices or conventional pads on IC's. The substrate can be glass silicon or alumina; a non-rigid substrate can be made of a polyimide material. The basic feature of the system is to locate the IC chip in substrate windows with integral mounting surfaces for die bonding. The beam lead conductors overhang the windows and register with the chip pads. A heated tip thermocompression bonder is used to make the interconnect bonds. Crossovers on the substrate are provided by air dielectric in a process where the plating support is subsequently removed by etching. Batch processing avoids discontinuities and joints other than at the chip pads. A 1 X 1 substrate containing 36 IC's for a simple 6-stage shift register has been constructed by MIT Lincoln Lab. [Ref. 24b]

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    b. "Metallization Systems for Silicon IC;s" (for NASA ERC NAS 12-132). Terry and Wilson (Motorola). Pp. 1580-1586.

    c. "Electromigration Failure Modes in Aluminum Metallization for Semiconductor Devices" (RADC F30602-67-C-0166 Proj 5519). James R. Black (Motorola). Pp. 1587-1594.

    d. "A Multichip Package Utilizing In-Cu Flip Chip Bonding." Youmans, Rose, & Greeman (Signetics). Pp. 1599-1605.

    e. "Measurement Standards for Integrated Circuit Processing." Bullis and Scace (National Bureau of Standards & GE). Pp. 1639-1646.

f. "Void Formation Failure Mechanism." Bernard Selikson (GE, Syracuse). Pp. 1594-1598.

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23. "An Up-to-Date Look at Thick Films." John J. Cox, Jr. and Donald T. DeCoursey. *EDN,* September 15, 1969. E. I. duPont de Nemours & Company.

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    a. "The Impact of Reliability Requirements on LSI Technology." Schnable, Keen & Schlacter (Philco-Ford). February 18, 1970, p. 146.

    b. "Rigid and Non-Rigid Beam-Lead Substrates." Bachner, Cohan, McMahon (MIT Lincoln Lab.). February 19, 1970, p. 94.

    c. "A Diode Coupled Bipolar Transistor Memory Cable." Lynes and Hodges (Bell Telephone Labs.). February 20, 1970, p. 44.

25. *Microelectronics and Reliability.* Vol. 5, No. 1 (February 1966).

a. "The Reliability of Integrated Circuits." Mackintosh and Elliott (Automation Microelectronics, Ltd.). Pp. 27-37.

b. "Welded and Bonded Connexions for Microelectronics." D. J. Clareke (Royal Radar Establishment). Pp. 73-83.

26. *Proceedings: 1967 Annual Symposium on Reliability.*

a. "Microelectronics Reliability." Charles Eliot (Raytheon Company). Pp. 349-358.

b. "Reliability of Integrated Circuits by Screening." T. J. Nowak (Autonetics Div. of North American Rockwell). Pp. 365-375.

27. "What's Wrong with Mil-Std-883." Bob Pease (Philbrick/Nexus). *EEE*, January 1970, p. 42.

28. "Interconnection of Monolithic Integrated Circuit Through the Use of Advanced Materials and Techniques." Bagrowski, Konsowski, and Spencer. *Transactions of IEEE on Parts Materials and Packaging*, Vol. PMP-2, No. 4, December 1966, pp. 90-98.

APPENDIX B

EFFECTIVENESS OF NDT VERBAL PRESENTATIONS

As a result of this tour we feel that the method of presenting information by a balanced team representing NASA as well as the contractor in direct confrontation with interested organizations has several distinct advantages over the more conventional means of reporting. It is our opinion that information resulting from R&D programs of immediate utility to industry in general should be conveyed by means of verbal presentations to cognizant segments of industry. In this way NASA receives the maximum return on investment because the techniques developed can be immediately applied by industry and the U.S. government derives the greatest possible benefit for the tax payer's dollar.

During the NDT tour, NASA and WVS representatives gave the presentations to 266 management and supervisory personnel representing a large cross section of the aerospace industry. Considering that these 266 individuals will also spread the word within their own organizations, we believe the money spent on presentations of this nature to be more than justified.

The advantages unique to this method of information dissemination observed during the NDT presentations are summarized below.

1. Presentations are made only to interested organizations

This fact was assured in the following manner:

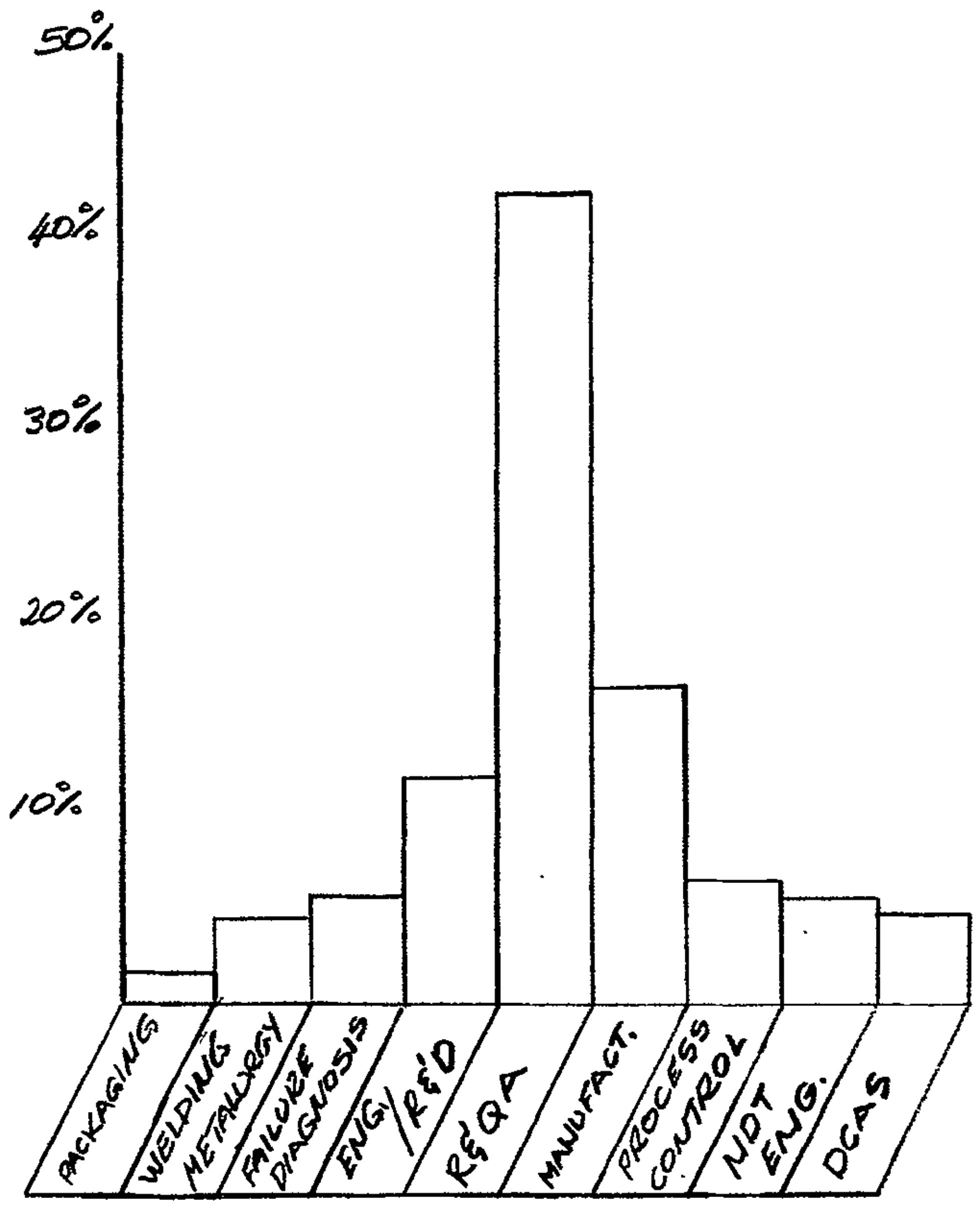
- Contact first made by telephone to a responsible individual within selected organizations.
- This man surveys his own and other divisions to establish their interest in the subject matter.
- Once interest has been confirmed, a formal letter describing the subject material to be covered is circulated by the original contact and firm commitments regarding the presentation date and time are made.

2. Only qualified personnel receive presentation

- The qualifications of the people to attend the presentations may be preselected in the program's best interest. In the case of the NDT presentations, it was decided mutually by NASA/ARC and WVS that the seminars be directed toward supervisory and management level people in the areas of reliability, quality control, and manufacturing. By so doing it was felt that the decision-making segment of the industry would be exposed to the information. Also, it was agreed that management types would be best able to assess the value of NDT instrumentation for their particular application. The distribution of NDT attendees by classification is shown in the figure appearing on page 66.

3. Personal contact with interested people assures maximum exposure and precludes the necessity for reading lengthy and complicated formal reports

- It is a fact that the distribution of formal reports to all concerned individuals is next to impossible to achieve. This is true because the



DISTRIBUTION OF ATTENDEES AT NDT SEMINARS BY CLASSIFICATION interest of an individual within a particular company cannot be predetermined remotely either by the R&D contractor or NASA. For instance, in the case of the NDT presentations many of the people attending had either not seen copies of our reports or had no prior knowledge of the program. Further, many people when faced with a voluminous and complicated report will not or cannot take the time to read it.

Personal contact with the people who performed the work on a particular contract assures the maximum dissemination of information in the shortest possible time.

4. Problems unique to particular organizations are resolved on the spot.

   o All companies do not have identical product, package configurations or manufacturing methods. Therefore, the practical aspects of implementing technologies and instrumentation developed as the result of an R&D effort will differ considerably. This fact was noted on the NDT tour and specific questions concerning the problems of NDT implementation were answered and discussed during the question and answer period of the presentation. This aspect of an R&D program cannot be adequately treated by the conventional reporting method.

5. NASA can obtain a real time assessment of R&D program success.

   o Direct confrontation with people knowledgeable in subject being presented will reveal in short order whether or not the material is really of interest, whether the data and conclusions presented are valid, and what if any impact the information will have on industry. By noting the response at each presentation, an assessment of program effectivity becomes very evident. The NDT presentations clearly showed the need for an effective NDT cross-wire weld inspection device of the type discussed. Also, because of the many questions concerning the extension of the NDT techniques to microbonding of I.C.'s and semiconductors, it was clearly evident that there is a great deal of concern for bond integrity in microelectronic devices. It was apparent that visual techniques are proving highly unsatisfactory and the requirement for an effective NDT system is becoming very critical.

6. <u>Two-way exchange of information</u>

- Both NASA and WVS representatives utilized the opportunity presented by the tour to discuss and interchange ideas with other experimenters in areas not necessarily directly concerned with the subject. We feel that this is a fringe benefit that can greatly improve and enhance communication and human relationships between NASA and its contractors -- in other words, NASA is human after all and a part of the industry-government team endeavoring to invest the tax payer's dollar in the best interest of the nation.

APPENDIX C

List of organizations visited for verbal presentation of NDT program results.

Jet Propulsion Laboratories
Pasadena, California
Attendance 14

WEMS, Inc.
Hawthorne, California
Attendance 27

TRW, Inc.
Redondo Beach, California
Attendance 26

Aerospace Corp.
El Segundo, California
Attendance 10

Autonetics
Anaheim, California
Attendance 5

Motorola, Inc.
Phoenix, Arizona
Attendance 17

Martin Marietta, Denver Division
Denver, Colorado
Attendance 9

Ball Bros. Research Corp.
Boulder, Colorado
Attendance 19

Marshal Space Flight Center
Huntsville, Alabama
Attendance 39

Godard Space Flight Center
Greenbelt, Maryland
Attendance 23

General Electric, Aerospace Group
Valley Forge, Pennsylvania
Attendance 6

RCA, Astro Electronics Division
Princeton, New Jersey
Attendance 19

General Electric, Ordnance Division
Pittsfield, Massachusetts
Attendance 10

Raytheon Company
Lexington, Massachusetts
Attendance 17

Sippican Corp.
Marion, Massachusetts
Attendance 9

Westinghouse Corp.
Baltimore, Maryland
Attendance 16